ARI Research Note 95-23

Examining the Effect of Information Sequence

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Research and Advanced Concepts Office
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February 1995

United States Army
Research Institute for the Behavioral and Social Sciences

U.S. ARMY RESEARCH INSTITUTE
FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency Under the Jurisdiction of the Deputy Chief of Staff for Personnel

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Research accomplished under contract for the Department of the Army

Decision Science Consortium, Inc.

Technical review by

Michael Drillings

Accesion For	
NTIS CRA&I	☑
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail and / or Special
A-1	

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	1995, February	Interim Jul 90 - Jul 91

4. TITLE AND SUBTITLE

Examining the Effect of Information Sequence

5. FUNDING NUMBERS

MDA903-89-C-0134
0601102A
B74F
1901
C44

6. AUTHOR(S)

Adelman, Leonard; and Bresnick, Terry A.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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Suite 300
Reston, VA 22091-4369

8. PERFORMING ORGANIZATION REPORT NUMBER

--

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Research Institute for the Behavioral and Social Sciences
ATTN: PERI-BR
5001 Eisenhower Avenue
Alexandria, VA 22333-5600

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

ARI Research Note 95-23

11. SUPPLEMENTARY NOTES

Contracting Officer's Representative, Michael Drillings.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

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13. ABSTRACT *(Maximum 200 words)*

This paper describes a recent experiment conducted with Patriot air defense officers and using the Patriot air defense simulators at Fort Bliss, Texas. The experimenters found that, under certain conditions, the participants made different identification judgments and took different engagement actions depending on the sequence in which the same information was presented to them. This finding was consistent with theoretical predictions regarding how operators process information, and the hypothesis that their processing approach (or Heuristic) would result in biased judgments under certain conditions. Future research is directed toward investigating whether display modification can remove the observed judgmental bias. Generally, this experiment demonstrates the applied implications of basic research investigating human information processing, and the importance of understanding cognitive processes when developing computer systems.

14. SUBJECT TERMS

Expert judgment
Sequence effects
Army air defense
Judgment heuristics and biases
Hypothesis testing

15. NUMBER OF PAGES

22

16. PRICE CODE

--

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

EXAMINING THE EFFECT OF INFORMATION SEQUENCE

Content

ACKNOWLEDGEMENT

This experiment would not have been possible without the assistance of many people. We want to thank Paul Black, James Chinnis Jr., Julia Doherty, Freeman Marvin, and Jeff Mandel of Decision Science Consortium, Inc., Michael Drillings and Michael Kaplan of the Army Research Institute's Basic Research Group; Laurel Allender, Mark Levitt, and Michael Strub of the Army Research Institute's Ft. Bliss Field Unit, and Paul Richey, Frank Silock, and Andy Washko of the Army's Directorate of Training Development, Ft. Bliss, TX. The research was sponsored by the U.S. Army Research Institute under Contract No. MDA903-89-C-0134, to Decision Science consortium, Inc. The views, opinions, and findings contained herein are those of the authors and should not be construed as those of the Army or any of its representatives.

EXAMINING THE EFFECT OF INFORMATION SEQUENCE ON EXPERT JUDGMENT

INTRODUCTION

It is clear that military decision makers will be working increasingly with computerized systems intended to aid their cognitive processes and reduce their cognitive workload. What is less clear is whether these systems can be based on a growing body of cognitive research findings, and on the integration of these findings into theories that provide general design principles.

For example, there is substantial basic research (e.g., see the anthology by Kahneman, et al., 1982) demonstrating that people use heuristics (i.e., procedures or rules) to make many judgments and decisions. Moreover, the research indicates that these heuristics are in large part determined by the judgment task facing the person. For many tasks, these heuristics can result in systematic biases or errors in judgment. An important question given minimal investigation thus far is whether military personnel use specific heuristics when performing tasks employing computer systems and, if so, whether these heuristics result in systematic biases that can affect performance of these tasks.

This paper presents the results of an experiment investigating whether operators for the Army's Patriot Air Defense System employ an anchoring and adjustment heuristic when making "friend versus foe" identification judgments. If they do, then the belief updating model proposed by Einhorn and Hogarth (1987) and Hogarth and Einhorn (1989) predicts that operators' judgments will result in an "information order bias" under certain conditions and not others. In particular, their model predicts that when there is only one aircraft track on the Patriot display at a time and there is conflicting information about the aircraft -- a situation representative of that when the U.S.S. Vincennes shot down an Iranian airliner -- the same information will result in different judgments simply depending on the sequence (or order) in which the information is presented to the operators.

Before describing the experiment, the next section briefly overviews the Hogarth-Einhorn model. We want to note here that there is previous empirical support for the model using non-military and military tasks. For example, Asare (1990), Ashton and Ashton (1988, 1990), and Meisser (1990) present results consistent with the model's predictions using professional auditors. Serfaty, Entin, and Tenney (1989) present results showing an order effects bias for Army officers performing a situation assessment task. And Adelman, Bresnick, and Tolcott (1990) found results consistent with the model's predictions for an Army air defense task using a paper-and-pencil instrument. The current experiment examines whether these results would be replicated when Army air defense officers use the actual system.

THEORETICAL MODEL

Theoretically, the Hogarth-Einhorn model predicts that, when information is presented sequentially and a probability estimate is obtained after each

piece of information, people make new estimates by first anchoring on the current position, and then adjusting it by the degree to which the new information confirms or disconfirms this position. Since each new piece of information leads to a new anchor, recent information is weighted more than prior information, thereby resulting in a recency affect when information is presented sequentially. Moreover, the Hogarth-Einhorn model predicts that the larger the anchor, the greater the impact of the same piece of disconfirming information. For example, the higher one's probability that an unidentified aircraft is a friend, the greater the negative impact of new information indicating that it is a foe. Conversely, the smaller the anchor, the greater the impact of the same confirming information. Consequently, the order in which the same confirming and disconfirming information is sequentially presented is predicted to result in different final probability estimates, for information order is predicted to significantly affect the anchoring positions.

Figure 1 presents a notional representation of the model's predictions for the air defense task. We assume that after the first piece of information, the air defense operator thinks that the probability that the unknown aircraft is a friend is 0.65. For Order #1, the operator first receives confirming information further suggesting that the aircraft is a friend, and then disconfirming information suggesting that it is a foe. For Order #2, the same information is presented but in the opposite order. Receiving the same information in different ordered sequences is quite possible in the air defense task depending on the aircraft's flight path and actions, and the way the information is relayed to the operator. The predictions are that air defense operators will give a significantly higher probability of friend to Order #2 than to Order #1 simply because of the anchoring and adjustment heuristic we hypothesize they use to process information.

In the example just provided, the information was presented sequentially to the operator. This is the principle case for which the Hogarth-Einhorn model predicts that an anchoring and adjustment heuristic will result in an order effects bias. In contrast, when information is presented all at once, the Hogarth-Einhorn model predicts that the information will be considered in the aggregate or "globally." Consequently, the order in which confirming and disconfirming information is presented should have no effect on people's final probability estimates. This prediction is represented by the circle within a circle after information item #3 in Figure 1. That is, operators should have the same final probability estimate regardless of the information's order.

THE EXPERIMENT

This part of the paper is divided into five sections. The first section describes the participants and research site. The second describes the research design. The third section describes the experimental procedures. The fourth section presents the hypotheses. And the fifth section presents the results.

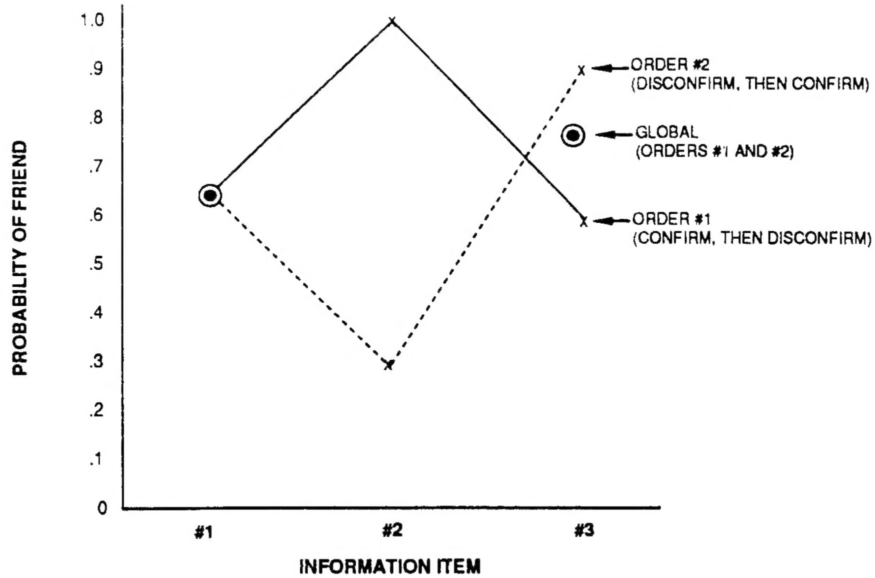

Figure 1: Notational Representation of Model's Predictions

Research Participants, Site, and Date

The experiment was conducted during the week of 29 October - 2 November 1990 with twenty-four officers trained as Tactical Control Officers for the Patriot Air Defense System. The task was implemented using the Patriot training simulators in the Directorate of Training Development at Ft. Bliss, TX.

Research Design

Independent Variables. Four independent variables were addressed when constructing the experiment. The first three listed below were used to develop the aircraft tracks or paths that the aircraft follows, displayed to the participants. The fourth was used to create the two different contexts under which the tracks were displayed.

The first independent variable was whether the first piece of information about an aircraft indicated that it was friendly, hostile, or unknown. The second independent variable was the order in which confirming and disconfirming information was presented early in an aircraft's track history. For Early Order #1, the second item of information confirmed the initial information and the third item of information disconfirmed it (CD). The opposite order was used for Early Order #2; that is, disconfirm then confirm (DC). The third independent variable was the order in which confirming and disconfirming information was presented late in an aircraft's track history. For Late Order #1, the fourth item of information confirmed the first information item, and the fifth item was disconfirming (CD). For Late Order #2, the opposite order (DC) was used for the fourth and fifth information items. (Note: For tracks whose first piece of information indicated unknown, the confirming information indicated a friendly aircraft and the disconfirming information indicated a hostile.)

Table 1 summarizes the research design for the three independent variables discussed above. The twelve cells in the matrix represent the twelve different tracks defined by crossing the three independent variables. Each of the twelve tracks was used in two scenarios. The two scenarios were used to create the two different contexts under which the tracks were displayed.

INITIAL INFORMATION	EARLY ORDER			
	CONFIRM (C)/DISCONFIRM (D) LATE ORDER		DISCONFIRM (D)/CONFIRM (C) LATE ORDER	
	CD	DC	CD	DC
UNKNOWNS				
FRIENDS				
HOSTILES				

Table 1: Research Design for Each Level of "Scenario" Factor

The scenarios represented the fourth independent variable. In the first scenario, there was only one aircraft track on the Patriot display at a time. Operators received information sequentially in this context, for there was nothing to distract them from observing each piece of information as it appeared on the display. In the second scenario, however, there were from five to ten aircraft tracks on the display at the same time. In this condition, operators have too many tracks to monitor each one continuously. Consequently, we reasoned that they would focus on tracks only when the tracks were close enough to be possible threats. At that time, they would call up the information about the track and, thus, receive all the information about it at once, not sequentially. We hypothesized that this would make the participants use a global information processing strategy instead of an anchoring and adjustment one.

Two steps were taken to minimize participants' ability to recognize previous tracks that had the same information presented in a slightly different order. We were particularly concerned about the operators recognizing previous tracks when there was only one track on the screen at a time.

First, we interspersed six other tracks among the twelve comprising the research design. These six tracks had no conflicting information. Three of the tracks were "obvious friends;" all information indicated that the aircraft was friendly. And three tracks were "obvious hostiles;" all information indicated that the aircraft was hostile.

Second, we created equivalent variations of the tracks. This was accomplished in a two-step procedure. First, we created "mirror images" of the tracks. For example, there were two tracks that had the first piece of information indicate friend, and had Early Order be Confirm then Disconfirm (CD). Since these two tracks had the same first three pieces of information,

we had one of the tracks appear on the left-hand side of the Patriot display and the other appear on the right-hand side. That is, the first half of one track was a mirror image of the other. They had, of course, different Late Order conditions. Therefore, in the second step, we designed the flight paths so that late order differences were not affected by the aircraft's position on the display. As a result, the tracks looked very different. However, each set of four friends, four foes, and four unknowns were equivalent except for the order in which the same information was presented to the operators.

Dependent Variables. Three dependent variables were used to assess if the independent variables affected the participants' judgments. The first dependent variable was the probability estimate that the participants gave for whether the aircraft was friend or foe.

The second was the participants' actual identification of the aircraft as friend, foe or unknown. For example, it is quite possible that information order significantly affects the probabilities given to two friendly aircraft but, in both cases, the aircraft are identified as "friends." The identification judgment, not the probability estimate, is the more important measure of air defense officers' judgments and is closer to the task they actually perform.

The third dependent variable was the participants' decision to engage an aircraft or not. The engagement decision is highly correlated with, but not identical to, the identification decision. The engagement decision also is affected by other factors, such as an aircraft's perceived threat. More importantly, however, it is the ultimate behavioral measure of air defense officers' judgments.

Experimental Procedures

The experiment was implemented on the Patriot training simulators at Ft. Bliss. Each session had three or four participants. The simulation system displayed the aircraft tracks to the participants at the same time. However, participants worked independently at separate Patriot consoles, and were free to process the track as they thought fit.

The session began with an introduction and brief overview of what probability estimates of friend or foe mean. A "Gulf War" situation (prior to the Gulf War) was presented to provide a context for the session. However, the display provided no unique geographic information. The description of the situation justified why participants were working in an autonomous mode; that is, without communications with other units or headquarters. By being in autonomous mode, the participants were solely responsible for their identification and engagement decisions.

Participants were also told that there had been some, but minimal compromise of the IFF Mode 3 response to Patriot's electronic interrogation signal; consequently, this response was not a perfect indicator of friendly aircraft. The description of the situation also indicated that it was equally likely that friendly and hostile aircraft were observed in order to nullify participants perceptions of this prior information. Finally, Patriot was

operated in the semi-automatic engagement mode to ensure that all the information was collected for all participants. However, Patriot continued to make identification recommendations based on its interpretation of the information.

For the "one track at a time" scenario, the track display and console were stopped after each information item for fifteen seconds for data collection. This was done to ensure that all data was collected at the same point in a track's history for all participants. The data was collected by an observer working with each participant. At each stopping point, the participant (1) told the observer the probability that the aircraft was friendly (or hostile); (2) identified the aircraft as friend, hostile, or unknown; and (3) indicated whether or not they would engage the aircraft. In addition, participants thought aloud throughout the session, which was tape recorded. If at any time in a track's history they indicated that they would engage the aircraft, the aircraft was considered engaged. However, they were told not to actually engage the aircraft so that we could continue to collect data on the two other dependent variables.

Figures 2 and 3 illustrate how this procedure worked for two tracks. Figure 2 represents one of the "obvious friends" used in the experiment. The air defense sector is represented by the inverted pyramid. The operator is located at the apex (bottom of figure) and protecting two assets. The aircraft first appears at point 1. The console is frozen, and the data collected, at point A. After fifteen seconds, the console is unfrozen and the track continues to point 2 where there is a Mode 1 and Mode 3 response to an automatic IFF interrogation at the Forward Support Coordination Line (FSCL). The console is frozen immediately after this (friendly) information is presented, and the data is collected. After fifteen seconds the track begins again. It goes right down one of the two safe passage corridors, just as a friendly aircraft should, for the rest of its flight path. The console is frozen, and data collected, at points C, D, E, and F.

Figure 3 shows one of the twelve tracks in the research design. It was conflicting information, the track first appeared at the FSCL, and the operator receives a Mode 1 and 3 IFF Response indicating friend. Then, the aircraft proceeds down the safe-passage corridor; this is confirming information. However, at point 2, the aircraft begins jamming friendly radar. This is disconfirming information. So, the Early Order is Confirm/Disconfirm. The aircraft stops jamming at point 3. This information is confirming because it suggests friend. Then, however, the aircraft goes out of and back into the safe passage corridor. Even though the aircraft is back in the corridor at point E where the fifth set of data is collected for this track, the "in-out move" suggests the aircraft is hostile and therefore, disconfirms the first piece of information. Consequently, the Late Order is also Confirm/Disconfirm.

Figure 4 is the mirror image of the track shown in Figure 3. Its flight path is the same except it is coming down the left-hand side of the display. The Late Order condition is, of course, different for this track. The "out-in move" is the fourth item of information (i.e., disconfirming) and "stopped jamming" is the fifth information item (i.e., confirming). Consequently, its Late Order is Disconfirm/Confirm.

TRACK 18

1. Track appears at point 1
2. Auto IFF at FSCL at point 2 (Mode 1, Mode 3 response)
3. Follows corridor to points 3 and 4

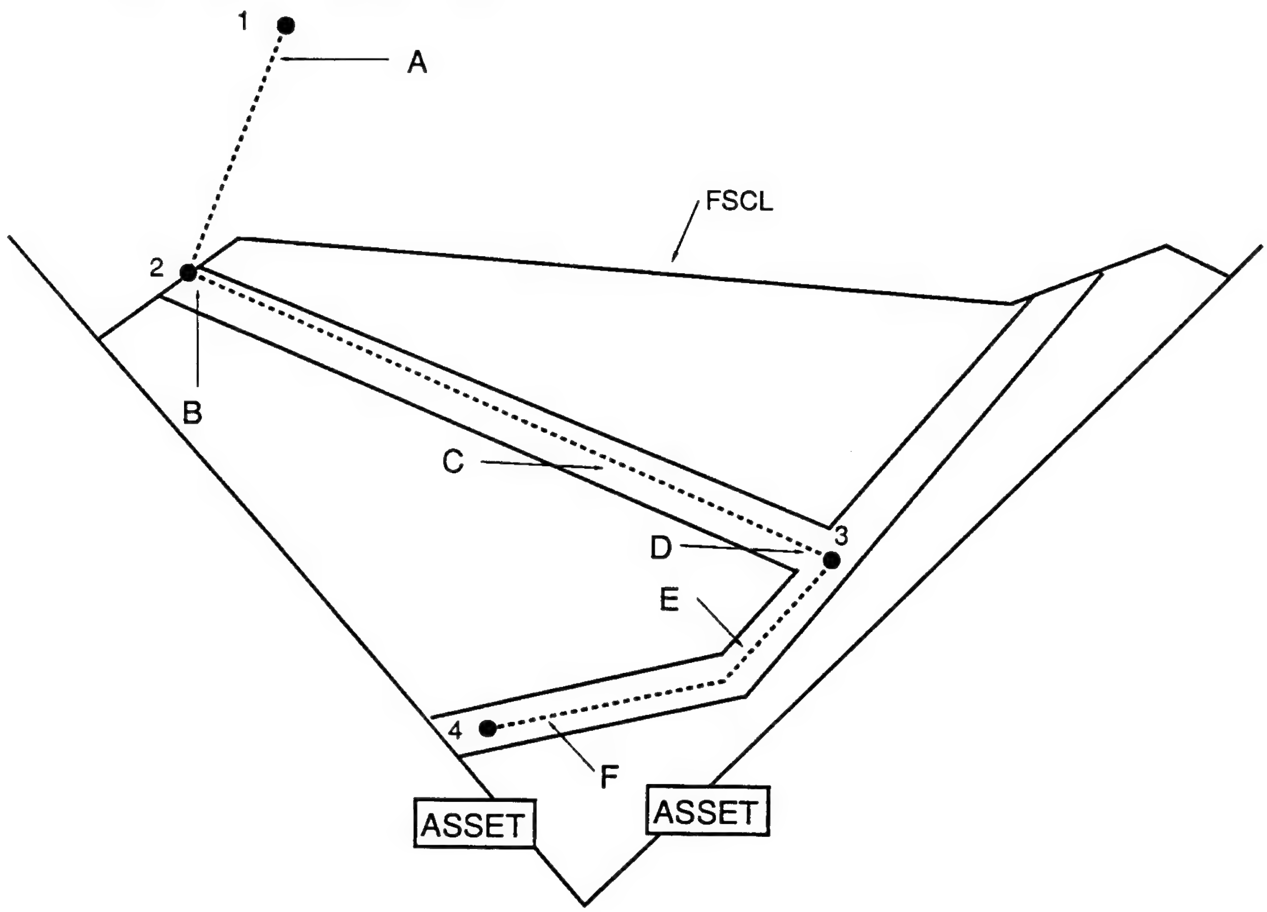

Figure 2: Aircraft Track for a Obvious Friend

TRACK 8

1. Track appears at point 1 along FSCL, auto IFF (Mode 1, Mode 3 response)
2. Track follows corridor to point 2, starts jamming
3. Stops jamming at point 3
4. Leaves corridor at point 4
5. Returns to corridor at point 5, continues in corridor to point 6

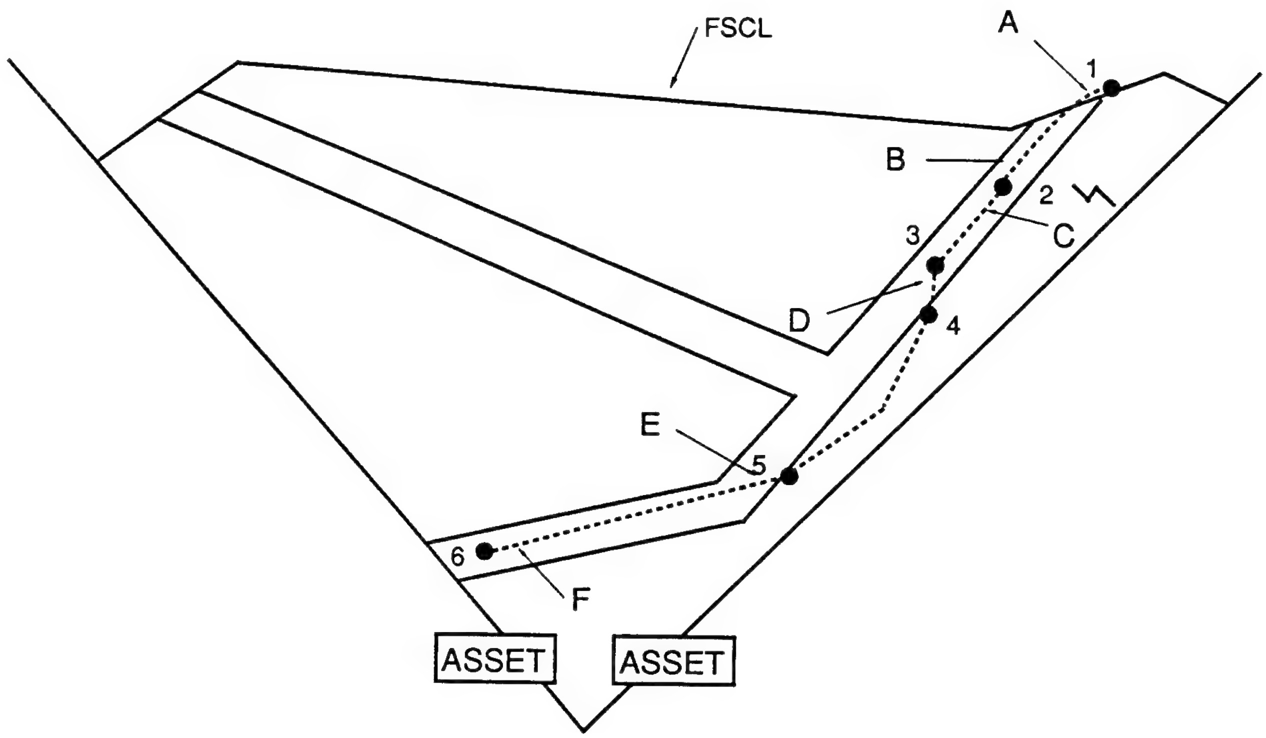

Figure 3: Friendly Track with Conflicting Information

TRACK 16

1. Track appears at point 1 along FSCL, Auto IFF (Mode 1, Mode 3 response)
2. Follows corridor to point 2, starts jamming
3. Leaves corridor at point 3, returns at point 4, stops jamming at point 5
4. Continues down corridor to point 6

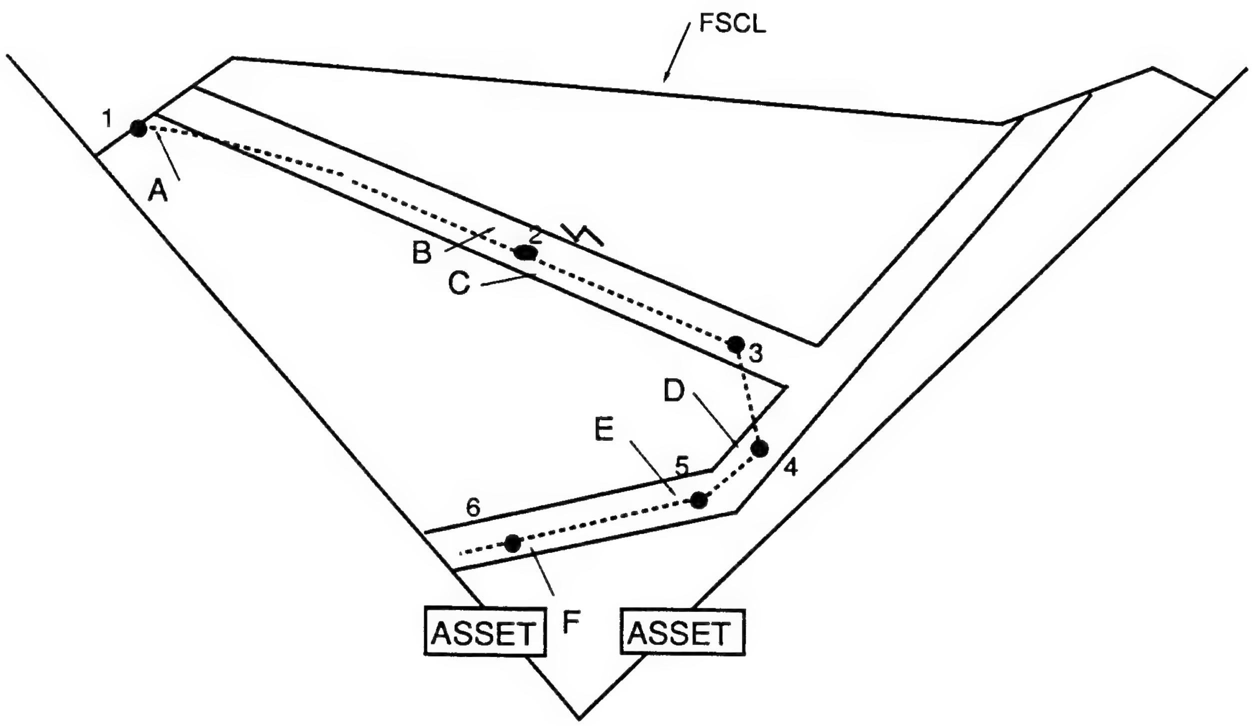

Figure 4: "Mirror Image" Friendly Track

The displays were not stopped for the "many track" scenario in order to maintain time pressure on the participants. Instead, at a pre-determined point for each of the twelve tracks comprising the research design, participants were told that in fifteen seconds they would have to tell the observer their probability, identification, and engagement decision for the track. This point was determined so that the aircraft would be at point E for the track. Pilot-testing indicated that this was enough time to hook the track and call-up information about it. No two design tracks were on the screen at the same time, and each was interspersed with 5-10 filler tracks. The "many track" scenario was always the second scenario for logistics reasons.

It is important to emphasize that (a) the two scenarios and (b) tracks with conflicting information represent situational contexts that can occur. When the U.S.S. Vincennes shot down the Iranian airliner, there were only two aircraft tracks on its display. And, during the Gulf War, there was often only one track on the Patriot display at a time. Although these tracks represented high speed tactical ballistic missiles that were automatically engaged by Patriot, they could, of course, have been aircraft.

More routinely, the Army air defense community has trained for the "many track" scenario because of its focus on Europe. And it has typically trained for tracks without conflicting information. However, it is well aware that tracks can have conflicting information, as illustrated by the Vincennes tragedy. In addition, tracks with conflicting information sometimes occur in Europe.

Hypotheses

We predicted that information order would affect all three measures of the operators' judgments only when the information was presented sequentially (i.e., for the "one track at a time" scenario), but not when it was presented all at once (i.e., for the "many track" scenario). Consistent with the Hogarth-Einhorn belief updating model, we predicted this would occur because operators would use sequential anchoring and adjustment heuristic when processing information in the former case, and a global information processing strategy in the latter. Only the sequential anchoring and adjustment heuristic was predicted to result in an information order bias.

Results

Before examining the data for the tracks with conflicting information, which comprised the research design, we performed two manipulation checks. First, we examined the data for the tracks without conflicting information (i.e., the "obvious friends" and "obvious hostiles") to determine if the operators treated them as such. The data indicated that they did. Specifically, the mean probability of friend estimate for the three "obvious friends" at Point E was 0.91. On the average, 22 of the 24 participants had identified them as friends by Point E, and there were no engagements. In contrast, the mean probability of friend estimate for the three "obvious hostiles" was 0.12 at Point E. On the average, 21.33 of the participants had made a "hostile" identification by Point E and, on the average, there were 17.33 engagements by Point E.

The second manipulation check focused on the twelve tracks comprising the research design. We wanted to make sure that there was only one new piece of information about a track each time the display was frozen for data collection purposes in the "one track at a time scenario". If two pieces of information were presented in between data collection stops, then it would be impossible to assess the effect of each information item. More importantly, if two pieces of information were presented together then, according to the Hogarth-Einhorn belief updating model, the operators would use a global processing strategy instead of a sequential anchoring and adjustment heuristic for the "one track at a time" scenario. Consequently, we would be unable to ascertain whether a failure to find the hypothesized "information order bias" would be due to an experimental manipulation failure or the failure to reject the null hypothesis, which was that information order would have no affect on air defense officers' judgments.

The second manipulation check was of particular concern because pilot testing had indicated that it was extremely difficult to construct the tracks so that two pieces of information did not appear together. This difficulty occurred because the training simulators were not designed to have the precision required to construct the kinds of tracks needed for the experiment. There was only one month between the pilot test and the dates for conducting the experiment. These dates were, so to speak, fixed in stone. Corrections were being made on the tracks right up to the day before the experiment began.

Careful examination of hard-copies of the displays after the experiment was completed indicated that a number of cells in the design were not implemented perfectly. Despite all the efforts of participating research personnel, sometimes two pieces of information (instead of one) appeared on the Patriot display at critical times prior to obtaining participants' judgments in the "one track at a time" scenario. The <u>unshaded</u> portion of the boxes in Table 2 indicate which half of a track's history was <u>implemented perfectly</u>.

INITIAL INFORMATION	EARLY ORDER			
	CONFIRM (C)/DISCONFIRM (D) LATE ORDER		DISCONFIRM (D)/CONFIRM (C) LATE ORDER	
	CD	DC	CD	DC
UNKNOWNS				
FRIENDS				
HOSTILES				

Table 2: Unshaded Boxes Indicate Which Half of a Track's History was Implemented Perfectly

The rest of this section presents the results of the analysis for (1) the early order manipulation for the two Unknown tracks that were implemented perfectly, (2) the Late Order manipulation for the three Unknown tracks whose late order manipulation was implemented perfectly. Each analysis is presented, in turn.

Early Order: Unknown Tracks. We began by first calculating the difference score for each participant's probability estimates between Points C and A for the two Unknown tracks. Difference scores were used to control for differences in participants' starting probability estimates at point A. Then, we performed a within-subject Analysis of Variance (ANOVA) using the SAS software package for Personal Computers to assess whether there was a significant mean difference in the difference scores for (1) the Unknown track with a CD early order, and (2) the Unknown track with a DC early order. There was not; the mean difference score for each track was essentially zero. This indicates that, for the one test performed, the order of information early in a track's history had no effect on operators' judgments for the "one track at a time" scenario.

Late Order: Unknown Tracks. We calculated the difference score for each participant's probability estimates between Points E and C for the three Unknown tracks that were implemented perfectly for the "one track at a time" scenario.

Difference scores were used to control for differences in participants' starting probability estimates at point C. The difference scores were not significantly different.

Late Order: Friendly Tracks. We calculated the difference score for each participant's probability estimates between Points E and C for the two Friendly tracks that were implemented perfectly for the "one track at a time" scenario. These two tracks, referred to as Tracks #8 and #16, are the respective tracks shown previously in Figures 3 and 4. Both tracks have a Confirm/Disconfirm (CD) early order, and Track #16 has a Disconfirm/Confirm (DC) late order.

Consistent with our hypothesis, Track #8 had a lower mean difference score than Track #16; -0.10 versus +0.03. A within-subject ANOVA found this difference significant at the $p = 0.05$ level. This finding supports the predictions of the Hogarth-Einhorn model, and suggests that the participating operators were using an anchoring and adjustment heuristic to process information in the "one track at a time" scenario.

We then added Track #7 to the analysis. The early order manipulation for Track #7 was not implemented perfectly, but the late order manipulation was. The late order manipulation for Track #7 was Disconfirm/Confirm. A within-subjects ANOVA found the E-C difference score for Tracks #7 and #8 to be significantly different at the $p = 0.02$ level. These results replicate those for Tracks #8 and #16. The mean difference scores for Tracks #7, #8, and #16 are presented in Figure 5.

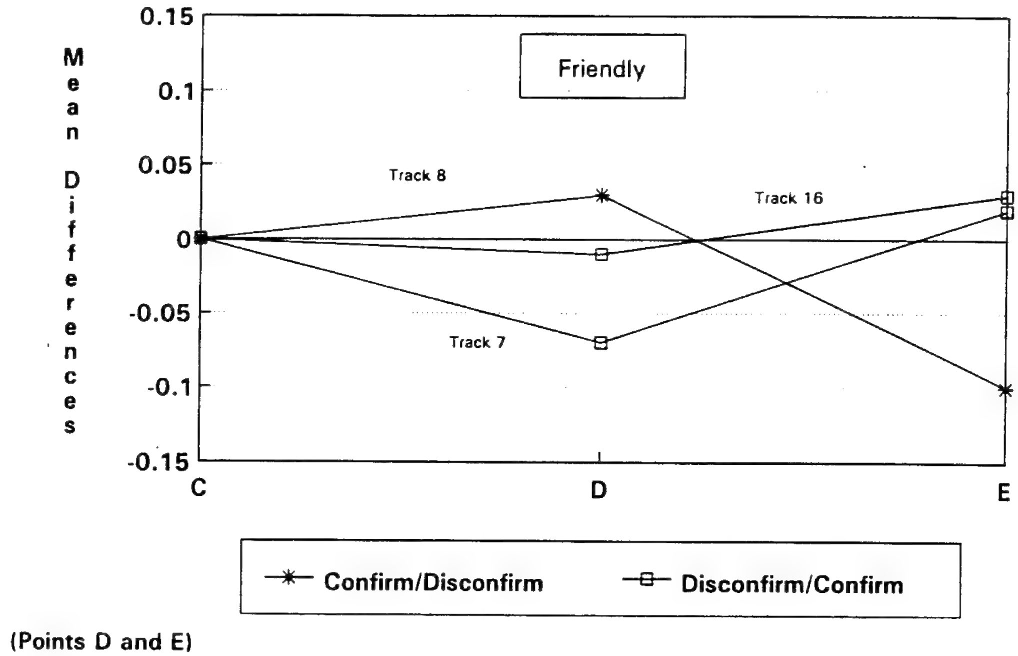

Figure 5: Mean Differences for Friendly Tracks #7, #8, #16

The above analysis indicates that the order of information late in the history of Tracks #7, #8, and #16 did affect operators' probability estimates. We now address whether it affected the operators' identification judgments. We could not perform a chi-squared test because each participant made an identification for each track; consequently, the entries in a chi-squared table would not be independent. However, we could use all the information to perform a test of marginal homogeneity. This test assessed whether the distribution of identifications was significantly different for the three tracks.

Table 3 presents the identification matrix for Tracks #7, #8, and #16. This is the matrix used in the test of marginal homogeneity. Although Track #8 has three more "hostile" identifications than either Track #7 or #16, the distribution of identifications look quite similar for the three tracks. This observation was supported by the marginal homogeneity test, which found that the distributions were not significantly different.

	IDENTIFICATION		
	HOSTILE	UNKNOWN	FRIEND
TRACK #8 (CD)	7	7	10
TRACK #16 (DC)	4	7	13
TRACK #7 (DC)	4	10	10

$X_4^2 = 2.65$, $P = .62$

Table 3: Identification Matrix for Tracks #7, #8, and #16 at Point E

Next, we examined whether there was a difference in the distribution of engagement decisions for the three tracks. There were no engagements for any of the three tracks at Point C. Table 4 shows the number of engagements for each track at Point E. As would be predicted by the Hogarth-Einhorn model, there were more engagements for Track #8 than Tracks #7 and #16. Moreover, the test of marginal homogeneity found this distribution to be significant at the p = 0.01 level. Not only did the Late Order manipulation affect operators' probability estimates for these three tracks, it affected their engagement decisions as well.

	ENGAGEMENT	
	NO	YES
TRACK #8 (CD)	15	9
TRACK #16 (DC)	19	5
TRACK #7 (DC)	21	3

$X_2^2 = 8.73$, $P = .013$

Table 4: Engagement Matrix for Tracks #7, #8, and #16 at Point E

But why was there a significant difference in the distribution of engagements and not the identifications? Examination of the data indicates that all seven participants who identified Track #8 as "hostile," engaged it. In addition, two of the participants who identified Track #8 as "friendly" at Point E, engaged it between Points D and E. That is, they engaged the track when it began the "out-in move" shown in Figure 3. The "out-in-move" is disconfirming information. It is critical information suggesting a hostile aircraft, and it occurred late in the track's history. Even though both participants later said the aircraft was a friend after it had returned to the safe-passage corridor, they had long since shct it down.

The final analysis focused on the "all at once" scenario. Consistent with the Hogarth-Einhorn model, the type of scenario did affect the results. Table 5 presents the mean probability of friend estimates for Tracks #7, #8, and #16 at Points E and F for both scenarios. As can be seen, the mean estimate for Track #8 only appears significantly lower for the "one track at a time" scenario (i.e., Scenario #1). As predicted, the mean probability estimates for the three tracks are about the same for the "all at once" scenario (i.e., Scenario #2). The interaction for the 2 Scenario by 3 Tracks within-subjects ANOVA approached significance ($p = 0.09$) at Point E, and was significant ($p = 0.03$) at Point F.

	Mean Probabilities at Point E		
	Track #7	Track #8	Track #16
"One at a Time" Scenario (Scenario 1)	.65	.51	.66
"All at Once" Scenario (Scenario 2)	.63	.62	.67

	Mean Probabilities at Point F		
	Track #7	Track #8	Track #16
"One at a Time" Scenario (Scenario 1)	.75	.58	.69
"All at Once" Scenario (Scenario 2)	.72	.69	.72

Table 5: Mean Probability of Friend Estimates for Tracks #7, #8, and #16 for Both Scenarios

The type of scenario did not affect the identification decision for Track #8 at Point E. However, it did affect the engagement decision. Table 6 shows the engagement decisions the 24 air defense officers made for Track #8 in the two scenarios. As can be seen, eight of the nine participants who engaged Track #8 in the "one track at a time" scenario did not engage it in the "all at once" scenario. The test of marginal homogeneity was significant at the p = 0.04 level, indicating that the distribution of engagements for Track #8 was significantly different for the two scenarios. In contrast, the distribution of engagements was not significantly different for Tracks #7 or #16.

		ENGAGE: SC#2		
		NO	YES	TOTAL
ENGAGE: SC#1	NO	13	2	15
	YES	8	1	9
	TOTAL	21	3	24

$X_1^2 = 4.24$, $P = .04$

Table 6: The Engagement Decision Made for Track #8 in Both Scenarios at Point E

DISCUSSION

The experiment reported herein obtained results consistent with the predictions of the Hogarth-Einhorn belief updating model for the late order manipulation for three Friendly tracks (#7, #8, and #16). When information was presented sequentially in the "one track at a time" scenario, and a

probability estimate was obtained after each piece of information, the Confirm/Disconfirm late order manipulation resulted in a significantly lower mean probability of friend estimate, and a significantly larger number of engagements, than the Disconfirm/Confirm late order manipulation. These differences were not found when information was presented all at once. These results support the hypothesis that air defense officers use an anchoring and adjustment heuristic when information is presented sequentially, and a more global aggregation strategy, such as a weighted averaging strategy, when information is presented all at once. Finally, it is important to emphasize that these results were obtained when information was presented on the Patriot display, and that they replicate previous findings obtained with a paper-and-pencil instrument (Adelman, Bresnick, and Tolcott, 1990).

These results must, however, be tempered by three caveats. First, many of the cells in the design were not implemented perfectly. In particular, there was only one Friendly track (Track #8) whose Confirm/Disconfirm late order manipulation was implemented perfectly. Second, there was no "late order" effect for the three Unknown tracks whose late order manipulation was implemented perfectly. And, third, there was no "early order" effect for the two perfectly implemented Unknown tracks. Consequently, one must be cautious in our conclusions about the generality of the observed "information order bias." Further research is needed to address these caveats. Nevertheless, the experiment indicates that such a bias can occur with highly trained military personnel, and that it can result in serious consequences; in particular, an increase in the probability of engaging a friendly aircraft.

Actions in the recent Gulf War have clearly demonstrated that Patriot air defense operators performed extremely well, and that the Patriot air defense system is an excellently engineered weapon system. Our findings do not detract from these facts. However, they do suggest that these high performance levels might be even further enhanced by considering how operators process information. Future research is directed toward (1) investigating the generality of the observed order effects, and (2) whether display modifications designed to facilitate a global processing strategy can remove the information order bias. More generally, the experiment report herein demonstrates the applied implications of basic research investigating human information processing, and the importance of understanding cognitive processes when developing computer systems.

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